(from "*mo*dulator/*dem*odulator"), any of a class of electronic devices that convert **digital** data **signals** into analog signals suitable for transmission over analog telecommunications circuits. A modem also receives modulated signals and demodulates them, recovering the digital signal for use by the **data** equipment. Modems thus make it possible for established **communications channels** to support a wide variety of data communication, such as **electronic mail** between personal **computers**, facsimile transmission between **fax machines**, or the downloading of audio-video files from a database server to a home computer.

Most modems are "**voiceband**"; *i.e.,* they enable digital terminal equipment to communicate over telephone channels, which are designed around the narrow bandwidth requirements of the human voice. So-called cable modems, on the other hand, support the transmission of data over wider-bandwidth cable and cable/fibre-optic channels. Both voiceband and cable modems are marketed as free-standing, book-sized modules that plug into a telephone or cable outlet and a port on a personal computer. In addition, voiceband modems are often installed as circuit boards directly into computers and fax machines. They are also available as small card-sized units that plug into laptop computers.

Modems operate in part by communicating with each other, and to do this they must follow matching protocols, or **operating standards**. Worldwide standards for voiceband modems are established by the V-series of recommendations published by the International Telecommunication Union's Telecommunication Standardization sector (ITU-T; formerly the International Telegraph and Telephone Consultative Committee, or CCITT). Among other functions, these standards establish the signaling by which modems initiate and terminate communication, establish compatible modulation and encoding schemes, and arrive at identical transmission speeds. Some operating specifications of prominent V-series standards are shown in the **Table**. Modems that transmit at the bit rates shown also have the ability to "fall back" to lower speeds in order to accommodate slower modems. "Full-duplex" standards allow simultaneous transmission and reception, which is necessary for interactive communication. "Half-duplex" standards also allow two-way communication, but not simultaneously; such modems are sufficient for facsimile transmission.

Data signals consist of multiple alternations between two values, represented by the binary digits, or **bits**, 0 and 1. Analog signals, on the other hand, consist of time-varying, wavelike fluctuations in value, much like the tones of the human voice. In order to represent binary data, the fluctuating values of the analog wave (*i.e.,* its frequency, amplitude, and phase) must be modified, or modulated, in such a manner as to represent the sequences of bits that make up the data signal. Modems employ a number of modulation methods to do this. The most important are **frequency-shift keying** (FSK), in which the carrier wave is shifted between two established frequencies, each frequency element representing one bit; **phase-shift keying** (PSK), in which the carrier wave is shifted among as many as eight different phase angles, each phase element representing up to three bits; and **quadrature amplitude modulation** (QAM), in which the signal is simultaneously shifted among four phase angles and a number of amplitude levels, each quadrature-amplitude element representing as many as six bits.

Each element of the modulated carrier wave is known as a baud. In FSK, employed by early voiceband modems beginning in the early 1960s, one baud represents one bit, so that a modem operating at 300 bauds per second (or, more simply, 300 baud) will transmit data at 300 bits per second (bps). In PSK and QAM, each baud represents several bits; with some modern modems operating at greater than 2,400 baud, it is possible to achieve data transmission rates as high as 28,800 bits, or 28.8 kilobits, per second. At the highest bit rates, channel-encoding schemes such as **trellis-coded modulation** (TCM) must be employed in order to reduce transmission errors. In addition, various source-encoding schemes can be used to compress the data into fewer bits, increasing the rate of information transmission without raising the bit rate.

Voiceband modems achieve the bit rates outlined above by modulating a carrier wave of approximately

EX "A"

1,800 hertz. Cable modems, by using QAM on a carrier wave with a frequency as high as 6 megahertz (6 million hertz), achieve a throughput of several million bits per second.

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